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Hydrol. Earth Syst. Sci. Discuss., 5, 1191–1226, 2008
www.hydrol-earth-syst-sci-discuss.net/5/1191/2008/

Hydrology and Earth System Sciences Discussions

Papers published in *Hydrology and Earth System Sciences Discussions* are under open-access review for the journal *Hydrology and Earth System Sciences*

Relations between topography, wetlands, vegetation cover and stream water chemistry in boreal headwater catchments in Sweden

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Received: 2 April 2008 – Accepted: 11 April 2008 – Published: 29 May 2008

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

A large part of the spatial variation of stream water chemistry is found in headwater streams and small catchments. To understand the dominant processes, taking place in small and heterogeneous catchments, spatial and temporal data with high resolution is needed. In most cases available map data has too low quality and resolution to successfully be used in environmental assessments and modelling. In this study 18 forested catchments (1–4 km^2) were selected within a 120×50 km area in the county of Värmland in western Sweden. The aim was to test if topographic and vegetation variables derived from official datasets were correlated to stream water chemistry, represented by DOC, Al, Fe and Si content. A GIS was used to analyse the elevation characteristics, generate topographic indices and calculate the percentage of wetlands and a number of vegetation classes. The results clearly show that the topography has a major influence on the occurrence of wetlands, which has a major influence on stream water chemistry. There were very strong correlations between mean slope and percentage wetland, percentage wetland and DOC, mean slope and DOC and mean topographic wetness index and DOC. The conclusion was that official topographic data, despite uncertain or low quality and resolution, could be useful in the prediction of headwater chemistry in boreal forested catchments.

1 Introduction

The chemistry of headwater streams is influenced by several landscape factors, which are related to geology, topography, climate and vegetation. During the 20th century, the human impact has also been significant, even for the smallest water systems, for example internal impact from land use measures and external impact from atmospheric deposition.

In Nordic boreal forests, some landscape factors are especially important for the development of stream water chemistry. One of these is the dominance of acidic bedrock

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(granite and gneiss), which results in acid-sensitive waters with a low content of dissolved substances. Another typical factor is the multitude of wetlands, which give a typical influence of dissolved organic matter, and consequently an increased natural acidity. This condition was for example clearly showed in data used by Andersson and Nyberg (2008), where about 60% of 68 randomly selected boreal headwater streams had a water colour (at medium flow) above 100 mg Pt/l, which corresponds to the highest class of five in the Environmental Quality Criteria, established by the Swedish Environmental Protection Agency (SNV, 2003).

Because of the severe acidification problems that have been a dominant environmental condition in forested areas in for example Sweden and Norway for several decades, and the ambition to separate the anthropogenic and natural acidity (SEPA, 2003), there is an interest in understanding how landscape factors influence stream water chemistry and especially those factors that govern the acidity.

The forested landscape in Sweden also experiences a long-term increase in dissolved organic matter. This could be exemplified by the trend for absorbance in River Klarälven (Fig. 1), which is a larger river situated near the area studied in this paper. The increase has been +50% over 40 years. The reason for the increase in this particular case is not fully investigated, but in the literature, climate changes (Clair et al., 1994; Freeman et al., 1995; Moore, 1998; Tranvik et al., 2002; Worall et al., 2003; Löfgren et al., 2003) and intensified forestry (Rosén et al., 1996; Lundin, 1999) are suggested as factors behind long-term changes in dissolved organic matter. A third potential factor can be decreased deposition of sulphur (Monteith et al., 2007).

There seems to be a gap between hydrological process-oriented research and the institutions that are dependent on methods and results in their work of solving regional and national environmental problems. The process knowledge is mostly available from studies of soil profiles, hillslopes or smaller catchments, and the need for tools is most obvious at a larger scale. One reason for the dominance of small-scale studies is the large spatial and temporal variability of factors that determine the hydrology and hydrochemistry. E.g. Wolock et al. (1997) showed that stream chemistry variability significantly decreased beyond catchment sizes of 3–4 km^2. Another reason concerns the possibilities to measure. Hooper (2001), e.g. concludes that “the instruments measure at a scale of decimetres when we need to understand the landscape at the scale of hectares or square kilometres”. A third reason might be that forest hydrology research has been closely linked to acidification research for several decades, and most of the acidification problems are found at higher altitudes near the headwaters.

There is a need for simpler, less time consuming and less costly methods to predict head water chemistry in the evaluation of the natural state of water quality, in order to make correct decisions for protection and restoration measures (SNV, 2003).

To reduce the gap between small-scale process knowledge and demands for better understanding at larger scales, one can study smaller elements that are aggregated into larger systems (Sivapalan and Kalma, 1995; Blöschl and Sivapalan, 1995). In doing this up-scaling, it is necessary to integrate new tools and data, such as late developments of GIS and official regional or national databases, into the analysis. For hydrology and hydrochemistry, the process knowledge gained from hillslope studies and small experimental catchments, needs first to be evaluated at the next larger scale, i.e. larger first-order and second-order streams. Blöschl (1995) suggested that instead of trying to capture everything when upscaling it would be better to identify dominant processes that control hydrological response at different scales, and then develop models to focus on these dominant processes. When going into larger scales, in-stream and hyporheic processes will be more important, and a crucial scale-step is when the streams flow into the first lake, which, depending on size, could have a large impact on hydrology and hydrochemistry.

1.1 Topography

Research results from the latest decades clearly show an influence of topography and wetland on stream water chemistry. The influence of topography is important since it controls the water subsurface contact time (Beven and Kirkby, 1979; Wolock et al., 1990; Dillon and Molot, 1997). Since the beginning of 1990's many methods for deriving these attributes from elevation data have been developed for use in hydrological applications. These attributes can be divided in two groups: primary and secondary topographic attributes.

Slope is a primary attribute that measures the rate of change of elevation and the direction of steepest decent, and the means by which gravity induces flow of water. Thus, it is of great significance in hydrology, affecting soil water content, flowpaths and residence times (Nyberg, 1995), and subsequently the chemical composition of surface waters (Beven, 1989; Wolock et al., 1989). Mean slope, based on a DEM with 50 m grid, was a variable that correlated with headwater chemistry in a previous study in the same region as in this paper (Andersson and Nyberg, 2008). Slope can be derived from elevation data by calculations in GIS or other computer softwares.

A secondary attribute, the topographic wetness index ln(a/tan β), where a is the upslope area per unit contour length and tan β is the slope, (Beven and Kirkby, 1979; Quinn et al., 1995), has frequently been used in modelling, and represents the wetness distribution in a catchment. A high value of the index means that the groundwater table is likely to be close to the ground surface. Subsequently, wetlands occur in areas with high values of the topographic wetness index, and it would be possible to predict locations of these by calculating topographic wetness indices over catchments. However, the possibility of doing this successfully depends on the relation between the spatial resolution of the data used in the index calculation and the typical length scales of the topography in the catchment (Rodhe and Seibert, 1999). The scale and terrain roughness of the analysed landscape and the resolution of the elevation data sets limits for the quality of the result (Moore et al., 1993; Wolock et al., 1994). Topographic indices can give valuable information about the distribution of soil moisture, location of potential saturated zones and source areas for runoff generation. The calculation of wetness indices is, however, sensitive to the used algorithm (Güntner et al., 2004). Especially the calculation of the upslope contributing area is crucial for the resulting pattern of saturated areas.

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1.2 Wetlands, vegetation cover and dissolved organic matter

In the Swedish boreal landscape, mire, divided into bogs, fens and mixed mires, is the most common wetland group (Löfroth, 1991). The occurrence of wetlands in boreal headwater catchments has in several studies shown a significant correlation with stream chemistry. Processes in peat and other frequently saturated organic soils produce humic substances that are transported to streams (Clair et al., 1994; Dillon and Molot, 1997; Mulholland and Kuenzler, 1979; Eckhardt et al., 1990; Koprivnjak and Moore, 1992; Hope et al., 1994; Mulholland, 1997). Hemond (1990) suggested that the most important processes take place in the riparian zone and depends on the stream flow generation. He was supported by Bishop et al. (1994) but questioned by Köhler et al. (1999) who concluded that the question of how organic acids enter streams still was open. Andersson and Nyberg (2008) concluded from a study of 68 headwater streams that it did not seem possible to predict humic substances in headwater streams by simply looking at the occurrence and locations of wetlands that are shown on official maps. Many small or hidden wetlands, or "cryptic wetlands" (Creed et al., 2003), with shallow peat cover are not shown on official maps because they are difficult or impossible to locate on aerial photos. Still, they are possible sources of production of dissolved organic matter in headwater catchments.

1.3 Objectives

The main objective of this study was to analyse the relations between topography, wetland and vegetation cover, represented by available official landscape data, and chemistry in boreal headwater streams in western Sweden. The aim was to determine "dominant landscape variables" that control the transport of dissolved organic matter, which is closely associated with natural acidification. However, data on soils (type, texture) and bedrock (type) was not included in the study as spatial datasets, since the available official maps have too low accuracy and spatial resolution. Furthermore, data on vegetation cover generally reflects the distribution of soil types well (Moore et al., 1991).

2 Study area

The 18 studied catchments were located within a 120×50 km area in the county of Värmland in western Sweden, between latitude 59 and 61 degrees N and longitude 12 and 14 degrees E (Fig. 2).

The dominant landform in the area is a hilly relief with some occurrence of faults and bare bedrocks in the south and higher but gentler hills in the north. The igneous bedrock consists mainly of acidic granites and gneisses with some occurrence of outcrops of magmatic hyperite and other rock types (Lundegårdh, 1995). The dominant soil type is till (>65%), peat (~20%) and some areas with sand and silt. The area contains lakes and wetlands while only a small part (<10%) is covered by farmland. The average elevation is approx. 200 m a.s.l. and the highest marine shoreline lies between 170 and 210 m a.s.l. within the area (Lundqvist, 1958, 1961). The annual mean temperature is 3–5°C, precipitation 800–900 mm, runoff 400–450 mm and evapotranspiration 400–450 mm. The precipitation normally falls as snow between November and mid March. The peak runoff normally occurs during the snowmelt period (Raab and Vedin, 1995). Coniferous forests (*Picea abies* and *Pinus sylvestris*) dominate the area. Within the area, only forestry can be counted as human impact of larger extent. However, the area has suffered from deposition of sulphur and nitrogen (Lundström et al., 1998).

3 Methods

1:250 000 and 1:100 000 scale official topographic maps from the Swedish Land Survey were used to delimit an area within the western part of the county of Värmland. 18 first-order streams were selected within the area for this study. The streams were part of two previous studies: 14 streams were taken from a study of 76 first-order streams, described by Andersson and Nyberg (2008). The other four were taken from a hydrological restoration project called "The Laskerud Project". The streams were first or second order. No arable or urban land was included in the 18 catchments. Forestry occurs in the catchments but was estimated not to be of the magnitude of influence to be considered in this study.

3.1 Spatial datasets

1:50 000 and 1:20 000 scale official topographic maps from the Swedish Land Survey were scanned and used for delineation of the catchments. Streams, wetlands and contour lines were digitized. The contours were used for delineation of catchments. The topographic maps were rather coarse in relation to the size of the catchments in this study. The maps show larger wetlands (>0.5 ha) and the generalization is rather strong. During field surveys some of the contour delineated water divides were found incorrect. Depending on the thickness of the vegetation and the roughness of the terrain the accuracy of the contour lines varied significantly.

An official 50 m resolution digital elevation model (DEM) and vegetation data were obtained from the Swedish Land Survey. The DEM has a mean elevation error of 2.5 m. The vegetation data was produced by interpretation of infrared aerial photos and has comparatively high spatial accuracy.

3.2 GIS analysis

ArcInfo GIS was used for calculations of area, elevation, slope and Topographic Wetness Index (TWI) layers for each catchment. TWI=ln(a/tan β), where a is the upslope area per unit contour length and tan β is the slope gradient. The calculation of the upslope area was based on a deterministic 8 model (O'Callagan and Mark, 1984) for flow over a terrain surface represented by the DEM. The mean value of the slope and TWI was calculated for each catchment and used in the statistical analysis.

The percentage of each vegetation type within the catchments was calculated. The digitized wetlands from the 1:50 000 scale maps were managed in the same way and compared with the mire types extracted from the vegetation data. The mires were classed into fen, bog and mixed mires.

3.3 Water sampling and chemical analysis

Water samples were collected at the outlet of each catchment four times at different flow situations during different seasons: summer low flow, summer medium flow (#1), autumn medium flow (#2) and spring high flow. 14 of the streams were sampled in 1998 and 1999 during four campaigns. The chemistry data from the four streams in the Laskerud Project were selected from a time series from 2003 and 2004. The selection was based on season and specific discharge. The filtered samples were kept dark and cool until the concentration of DOC [mg/l] was determined. The instrument used for measuring the DOC-concentration was a Schimadzu 500 carbon-analyser. Fe, Al and Si were analysed with ICP-OES (Varian).

The runoff was estimated by simple methods (bucket or float) when the samples were taken. The specific runoff was in average 0.8 $l/s/km^2$ at the low flow situation, 13 $l/s/km^2$ at the medium flow #1 situation, 11 $l/s/km^2$at the medium flow #2 situation and 30 $l/s/km^2$ at the high flow situation. During the high flow sampling round, seven streams were not sampled due to snow covered roads that made the sites inaccessible.

3.4 Statistical analysis

PCA analysis was initially performed to study the overall relations between topographic, wetland and vegetation variables. Correlation (Pearson) and linear regression analyses were then performed in order to investigate the covariation between landscape variables and water chemistry at different flow situations.

4 Results

4.1 Topographic characteristics

The mean size of the 18 catchments was 1.56 km^2 (Table 1). Most of the catchments were situated above the highest marine shoreline, which is at about 180–190 m a.s.l. Catchment L5 has been selected to visualize the spatially distributed data used in the analysis (Fig. 3a–c). L5 was the catchment with highest percentage of wetland, 20%. It was also the catchment with lowest mean slope, 4.1%. The topographic wetness index for single 50×50 m cells ranged from 9.6 to 19.1 with a mean of 12.4.

Mean slope and mean topographic wetness index were strongly negatively correlated to each other, which was expected since the calculation of TWI includes the slope in the denominator. The correlation coefficient of −0.95 indicated that the slope has a dominant influence in the TWI, compared to the upstream drainage area per contour length *a*.

4.2 Wetland characteristics

In average 7% of the area of the 18 studied catchments were covered with wetland (Table 2). The wetland percentage on the 1:50 000 scale maps was 0.7% larger than the percentage in the vegetation data. About 40% of the wetland was mixed mire according to the vegetation data.

There were only small differences in the distribution and location of wetlands in the two types of data sources. The errors are mainly caused by misinterpretations between wet coniferous forest and coniferous mire. There is no distinction between mire classes in the topographic map. Figure 4 exemplifies the distribution of fen, bog and mixed mire in Catchment L5. Bogs covered 11%, mixed mires covered 5.1% and fens covered 5.1% of the catchment. Figure 5 shows the same catchments' mire types represented in the vegetation database.

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4.3 Vegetation characteristics

The vegetation database included 22 vegetation types within the catchments, of which the 7 smallest were merged and categorized as "others". The catchments were dominated by mesic coniferous forest (77%). Dry coniferous forest covered 8.1% and moist coniferous forest 4.1%. Of the mire vegetation types the lawn type (2.0%) and carpet type (1.1%) was most common (Table 3). In Table 4 the occurrence of the different vegetation types in each catchment is listed.

There is a large heterogeneity regarding vegetation types within and between the catchments (Table 4). Catchment B008 and B109 only comprise five vegetation types while catchment B006 and L5 had twelve. The table also shows the frequency of the vegetation types. Mesic coniferous forest was found in every catchment. Moist coniferous forest was found in all but one, while others were less frequent.

4.4 Chemical characteristics

DOC was used as a measure of dissolved organic matter. The DOC levels in the studied catchments were relatively high (Table 5), and the temporal and spatial variations were large (Fig. 7). The highest levels were found for the low and medium flow samplings. The low and summer medium flow samplings had lower levels of DOC. Si, which is a measure of silicate weathering, had highest concentrations during the autumn medium flow and lowest during the spring flood.

Fe (Fig. 6), Al and Si were correlated to DOC (Table 6), and had similar seasonal patterns as DOC.

The greatest temporal variability was found in catchment B021 where the DOC level ranged from 0.11 at high flow to 0.35 at medium flow 2. In B021 the mean DOC level was 0.19 while it was as low as 0.02 in catchment B002.

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4.5 Relations between topography, wetland and vegetation

A principal component analysis (PCA) including all topographic and vegetation variables was carried out to investigate the relations between those two groups of variables (Fig. 8). The first principal component explained 40% of the total variation, and captured primarily the slope-related variation. The second component explained 22%, and described the variation related to elevation.

There was a group of variables that contributed most to PC1: mean slope, mean TWI, total wetland and coniferous forest of mire type. These four variables were also strongly correlated to each other. A further analysis of the relation between coniferous mire type and total wetland showed that a rather stable proportion of 40% of the total wetland in each catchment was of coniferous mire type.

In PC2, dry coniferous forest had the strongest (negative) correlation with altitude. This is probably a side-effect of the weak correlation between altitude and latitude. The mean altitude was slightly higher in the northern part of the study area, where the soil cover is somewhat deeper.

A correlation analysis for topographic and wetland variables was made (Table 7). The strongest correlation was found between mean topographic wetness index and wetland percentage estimated from the vegetation map (Fig. 9).

4.6 Relations between topography-wetland-mires classes and water chemistry

A correlation analysis including topography, wetland percentages and water chemistry (Table 8) showed moderate and strong pair-wise correlations between topography-wetland, wetland-chemistry and topography-chemistry. The chemistry referred to here is DOC and Fe during medium and high flow. The correlations between topography/wetland and DOC/Fe were especially high during high flow.

The classification of wetlands into bogs and fens did not give any stronger correlations in relation to water chemistry (Table 8). The class "Mixed mire" had stronger correlations than "Fen" and "Bog".

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Si was not significantly correlated to topography or wetland.

There was a strong correlation between mean topographic wetness index and DOC (Table 8, Fig. 10). It was strongest at the high flow situation and decreasing with decreasing flow.

5 Discussion

The results show several strong correlations between topography, wetlands and DOC. The vegetation data, however, did not bring much to the results, even if there were some significant correlations. The vegetation database was, however, useful for validation of the topographic map data.

The topography and wetland variables were stronger correlated to the water chemistry at medium (summer and autumn) and high flow (spring flood) than at the low flow situation (summer). This indicated that, for this 120×50 km area, the connection between the sources of dissolved organic carbon and the stream was weaker during low flow. One possible reason was the longer retention times for water in the ground and streams which gave more time for biological degradation of organic matter. The low flow situation also occurred during summer when the biological activity was high.

A previous study in the same region concluded that the variable "mean slope" was better correlated to DOC than the occurrence of wetlands in headwater catchments (Andersson and Nyberg, 2008). That study also concluded that better quality and higher resolution of spatial data are needed in order to make reliable estimates of influencing factors in head water catchments smaller than 1.5 km^2.

It is widely recognized that topographic analyses are sensitive to the resolution of the data source generalized. This affects all topographic attributes, but in varying ways. The resolution-dependence of slope and specific catchment area has been most intensively studied because of their regular application in hydrological modelling (e.g. Tarboton, 1997; Moore et al., 1993; Zhang and Montgomery, 1994). In this study a 50 m DEM grid was used for deriving the variables "slope" and "topographic wetness index", which were used in statistical analyses of the complex interactions taking place in small scale heterogeneous boreal catchments.

Beven (1997) criticized modellers deriving topographic indices from DEMs with grid sizes exceeding slope lengths in the landscape. Comparing the topographic wetness index grid with the wetland layer in this study was not a success. This was also tested by Rodhe and Seibert (1999) with varying results. Our study supports their conclusion that the geologic conditions modify the topographic control of the wetness. Sörensen and Seibert (2007) concluded that the DEMs with different grid resolution showed considerable differences in the TWI pattern. That statement will be a question for further studies in our study area when better elevation data is obtained.

The final conclusion is, however, that very strong correlations between DOC and mean topographic wetness index and wetland percentage (especially at high flow situations) indicate that available spatial data (official 1:50 000 scale topographic maps and 50 m DEM grids) could be used for predictions of stream water chemistry (DOC and iron) in headwater catchments in Swedish boreal forests.

Acknowledgements. The authors wish to thank Mistra (The Foundation for Strategic Environmental Research) and the multi-disciplinary research group MiljöFoCus at Karlstad University for funding. Maria Malmström is gratefully thanked for her work with chemical analyses.

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Table 1. Catchment and topographic characteristics.

	Area [km^2]	Lowest elevation [m a.s.l.]	Highest elevation [m a.s.l.]	Mean elevation [m a.s.l.]	Mean slope [%]	Mean TWI
Mean	1.56	172	282	236	8.9	11.8
Std dev	0.78	45	54	51	2.8	0.3
Min	0.97	86	201	150	4.1	11.2
Max	3.81	244	400	316	14.7	12.4
n	18	18	18	18	18	18

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Table 2. Descriptive statistics for wetland coverage estimated from topographic maps and from the vegetation database.

%	Topo. map	Vegetation data Fen	Bog	Mixed	Sum
Mean	7.7	1.6	2.3	3.1	7.0
Std dev	7.5	1.5	1.9	2.4	6.2
Min	0.5	0	0	0.2	0.2
Max	20.3	5.1	10.9	8.6	21.1
n	18	18	18	18	18

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Table 3. Vegetation types, total percentages (for all 18 catchments) and descriptions.

Vegetation type	Area [%]	Description
1 Coniferous forest, dry	8.1	Bare rocks, thin soil layer, lichens, mosses, mainly pines
2 Coniferous forest, mesic	76.8	Mosses, dwarf shrubs, blueberry, mainly spruce
3 Coniferous forest, moist	4.1	Mosses incl. forest Sphagna, dwarf shrubs, mainly spruce
4 Coniferous forest, wet	1.7	Mosses, low herbs, dwarf shrubs, spruce, waterlogged
5 Coniferous forest, mire	2.7	Fen or bog, Sphagnum spp, Ledum, pine and spruce
6 Deciduous forest, mesic	0.2	Cultivated soil, birch, aspen and other deciduous species
7 Deciduous forest, wet	0.1	Thick forest with birch, alder, viden, wet hummocky ground
8 Deciduous forest, mire	0.2	Fen, sparse vegetation, birch and viden
9 Dwarf shrub hummock mire	0.9	Hummocky peat, *Sphagnum* spp, shrubs and dwarf pines
10 Mire of lawn type	2.0	Fen or bog, lawn-like vegetation
11 Mire of carpet type	1.1	Fen or bog, wet, soft, carpet-like vegetation
12 Mire of peat mud type	0.1	Fen or bog, mudbottom vegetation, flarks
13 Plantation	0.7	Tree plantation on former open land, spruce or pine
14 Water	0.9	Open water or water with sparse vegetation
15 Others	0.3	Meadow, arable land, grassland, garden etc.

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Table 4. Occurrence of vegetation types in the catchments.

Catchment	Vegetation type 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	*n*
B002	×	×		×							×		×			5
B005	×	×	×	×	×	×		×			×		×	×	×	11
B006	×	×	×	×	×		×		×	×	×		×	×	×	12
B008	×	×	×	×	×											5
B016	×	×	×	×	×			×	×	×	×					9
B021		×	×		×	×	×	×		×	×					8
B024	×	×	×	×	×					×		×		×		8
B030		×	×		×	×			×				×			6
B032		×	×	×	×			×	×	×	×					8
B034	×	×	×	×	×	×				×					×	8
B106	×	×	×	×	×	×		×	×				×	×	×	11
B107	×	×	×	×	×					×	×					7
B109		×	×		×				×		×					5
B118		×	×		×				×		×		×		×	7
D1	×	×	×	×	×				×	×	×	×		×	×	11
L5	×	×	×	×	×		×	×	×	×	×			×	×	12
L69	×	×	×	×	×		×	×	×		×			×		10
L78		×	×	×	×		×	×	×	×	×			×	×	11
n	12	18	17	14	17	5	5	8	11	10	13	2	6	8	8	

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Table 5. Descriptive statistics for stream chemistry for four flow situations: low flow (L), medium flow (M1 and M2) and high flow (H). The unit for DOC is mg/l and for Al, Fe and Si it is μmol/l.

	DOC				Al				Fe				Si			
	L	M1	M2	H	L	M1	M2	H	L	M1	M2	H	L	M1	M2	H
Mean	18.8	19.7	14.4	12.6	18.8	19.6	14.9	9.1	26.4	19.4	12.2	8.3	106.0	105.2	115.1	81.8
Std dev	8.2	7.5	4.2	2.6	10.7	8.8	5.3	1.9	18.5	13.0	6.6	4.0	30.7	26.5	16.6	11.6
Min	6.8	8.2	7.3	7.9	3.9	5.9	6.9	5.8	2.5	4.7	2.7	2.6	54.4	70.0	93.5	68.2
Max	32.6	40.1	22.8	16.7	36.0	42.1	23.6	11.9	62.8	51.2	25.0	16.1	150.4	167.8	152.6	102.1
n	18	18	18	11	14	18	17	11	14	18	17	11	13	17	17	11

Table 6. Pearson correlations between the measured chemical constituents at medium flow #1 (M#1) and high flow (H). n=18 for M#1 and n=11 for H. The strongest correlations are highlighted with bold numbers. (* p<0.05, ** p<0.01).

	DOC (M#1)	DOC (H)	Al (M#1)	Al (H)	Fe (M#1)	Fe (H)
DOC (M#1)	1.00					
DOC (H)		1.00				
Al (M#1)	**0.72****		1.00			
Al (H)		0.23		1.00		
Fe (M#1)	**0.79****		**0.52***		1.00	
Fe (H)		**0.68***		**0.67***		1.00
Si (M#1)	−0.13		−0.16		0.19	
Si (H)		0.14		**0.62***		0.49

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Table 7. Correlations between topographic and wetland/mire class variables. n=18. The strongest correlations are highlighted with bold numbers (p<0.01).

	Mean slope	Mean TWI	Wetland (Topo. map)	Wetland (Veg. data)	Fen	Bog	Mixed mire
Mean slope	1.00						
Mean TWI	**−0.95**	1.00					
Wetland (Topo. Map)	**−0.84**	**0.88**	1.00				
Wetland (Veg. Map)	**−0.83**	**0.90**	**0.96**	1.00			
Fen	**−0.69**	**0.64**	0.54	**0.62**	1.00		
Bog	**−0.66**	**0.68**	**0.86**	**0.86**	0.47	1.00	
Mixed mire	**−0.66**	**0.79**	**0.78**	**0.82**	0.27	0.49	1.00
Coniferous forest mire	**−0.72**	**0.79**	**0.84**	**0.92**	**0.59**	**0.82**	**0.70**
Mire, lawn type	**−0.61**	**0.63**	**0.70**	**0.64**	0.23	0.64	0.54
Mire, carpet type	−0.58	**0.62**	0.56	**0.62**	**0.63**	0.34	**0.60**
Dwarf shrub hum. mire	−0.42	0.50	0.58	**0.67**	0.42	0.51	**0.60**

Table 8. Correlations between topographical/wetland variables and stream chemistry variables (L represents low flow, M#1 and M#2 medium flow and H high flow). The strongest correlations are highlighted with bold numbers ($p<0.01$).

		Mean slope	Mean TWI	Wetland (Topo. map)	Wetland (Veg. data)	Fen	Bog	Mixed mire
DOC (L)	*r*	−0.52	0.49	0.37	0.36	0.24	0.30	0.29
	n	18	18	18	18	18	18	18
DOC (M#1)	*r*	**−0.73**	**0.76**	0.58	**0.69**	0.56	0.36	**0.71**
	n	18	18	18	18	18	18	18
DOC (M#2)	*r*	**−0.72**	**0.73**	**0.60**	**0.62**	0.49	0.29	**0.67**
	n	18	18	18	18	18	18	18
DOC (H)	*r*	**−0.92**	**0.97**	**0.85**	**0.88**	0.52	0.61	**0.85**
	n	11	11	11	11	11	11	11
Al (L)	*r*	−0.21	0.17	0.01	−0.02	−0.12	−0.30	0.28
	n	15	15	15	15	15	14	15
Al (M#1)	*r*	−0.24	0.31	0.03	0.14	0.11	−0.31	0.50
	n	18	18	18	18	18	17	18
Al (M#2)	*r*	−0.16	0.22	0.02	0.05	−0.03	−0.40	0.48
	n	17	17	17	17	17	16	17
Al (H)	*r*	−0.05	0.10	−0.14	−0.08	−0.22	−0.48	0.47
	n	11	11	11	11	11	10	11
Fe (L)	*r*	−0.40	0.28	0.17	0.20	0.35	0.13	0.11
	n	15	15	15	15	15	14	15
Fe (M#1)	*r*	−0.58	**0.60**	0.39	0.52	0.40	0.19	**0.61**
	n	18	18	18	18	18	18	18
Fe (M#2)	*r*	**−0.67**	**0.69**	0.56	**0.61**	0.39	0.28	**0.73**
	n	17	17	17	17	17	17	17
Fe (H)	*r*	**−0.81**	**0.86**	0.71	**0.77**	0.45	0.42	**0.82**
	n	11	11	11	11	11	11	11
Si (L)	*r*	−0.16	0.19	0.35	0.25	−0.35	0.06	−0.16
	n	15	15	15	15	15	14	15
Si (M#1)	*r*	0.23	−0.32	−0.46	−0.34	−0.23	−0.48	0.23
	n	18	18	18	18	18	17	18
Si (M#2)	*r*	−0.16	0.02	0.17	0.15	0.06	0.24	−0.16
	n	17	17	17	17	17	16	17
Si (H)	*r*	0.04	−0.22	−0.28	−0.18	0.04	0.01	0.04
	n	11	11	11	11	11	10	11

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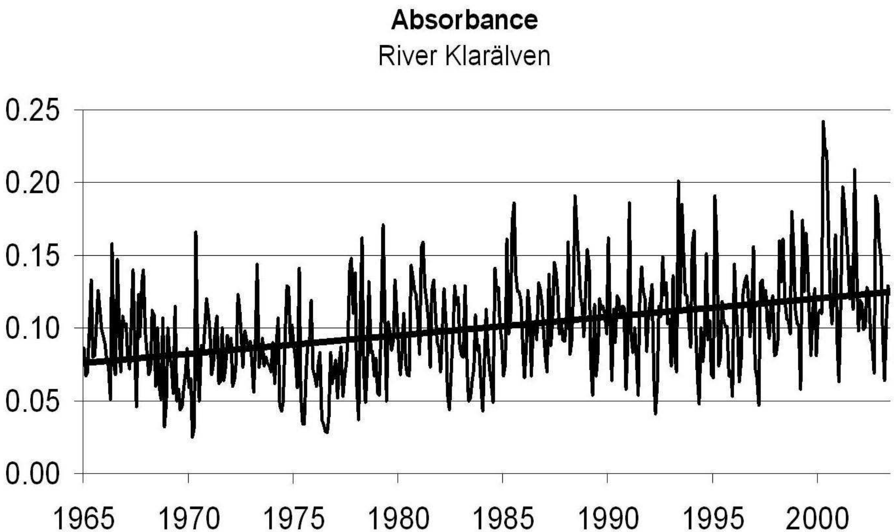

Fig. 1. Absorbance measured monthly at Edsforsen in River Klarälven, Sweden, between 1965 and 2003. The catchment area upstream the sampling point is 8570 km^2.

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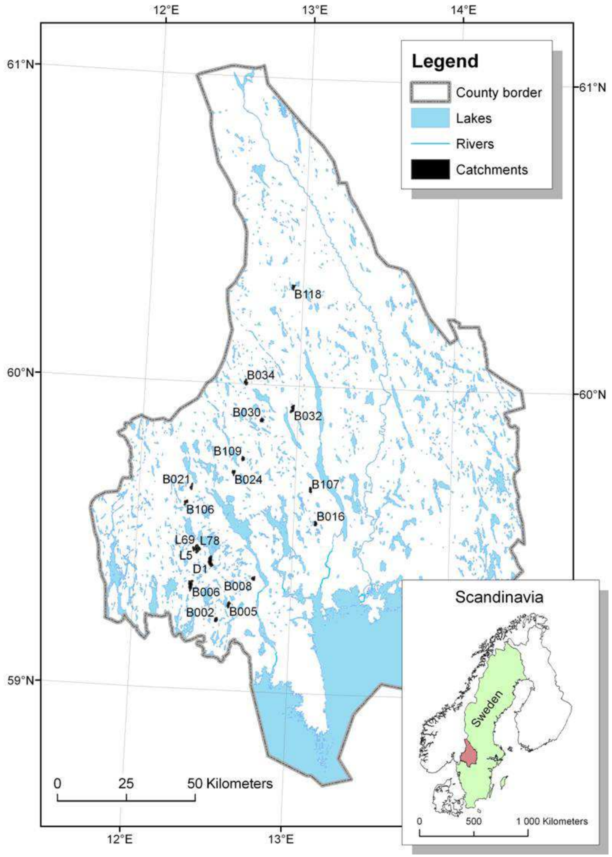

Fig. 2. Study area with 18 catchments in a 120×50 km area in the county of Värmland, Sweden.

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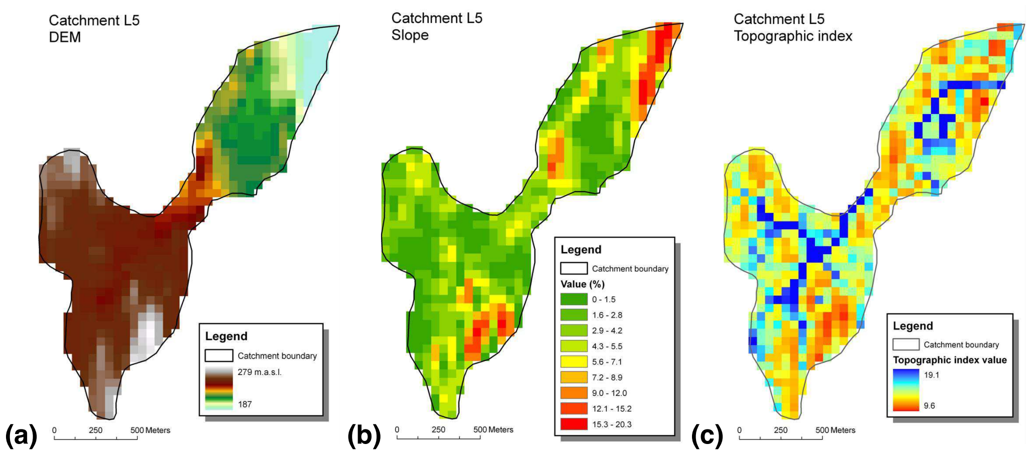

Fig. 3. Topographic description of example catchment L5. **(a)** Elevation [m a.s.l.], **(b)** Slope [%] and **(c)** Topographic wetness index.

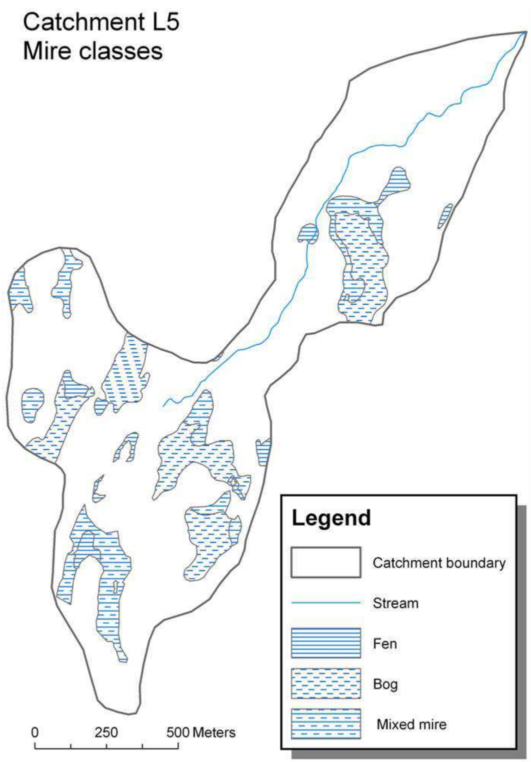

Fig. 4. Mire classes in catchment L5.

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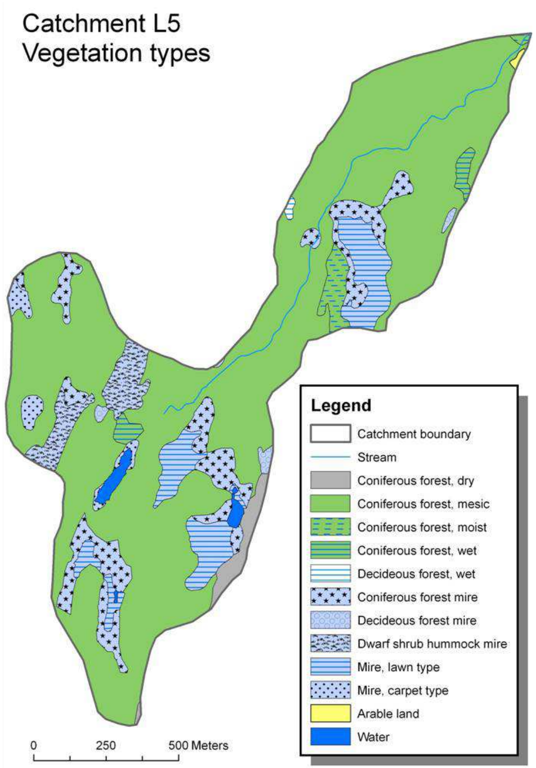

Fig. 5. Vegetation types in catchment L5.

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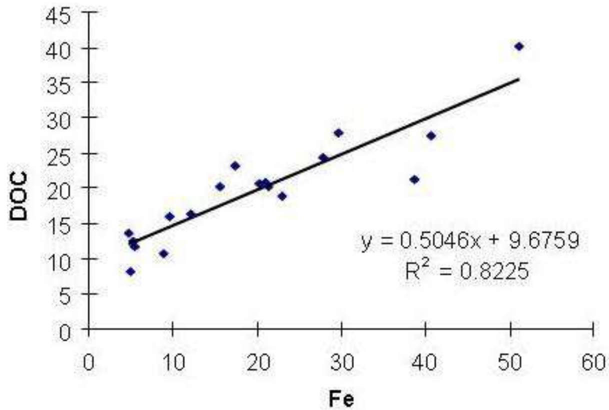

Fig. 6. Regressions showing the significant relationship between iron and DOC in the medium #1 flow situation. Units for DOC is mg/l and for Fe μmol/l.

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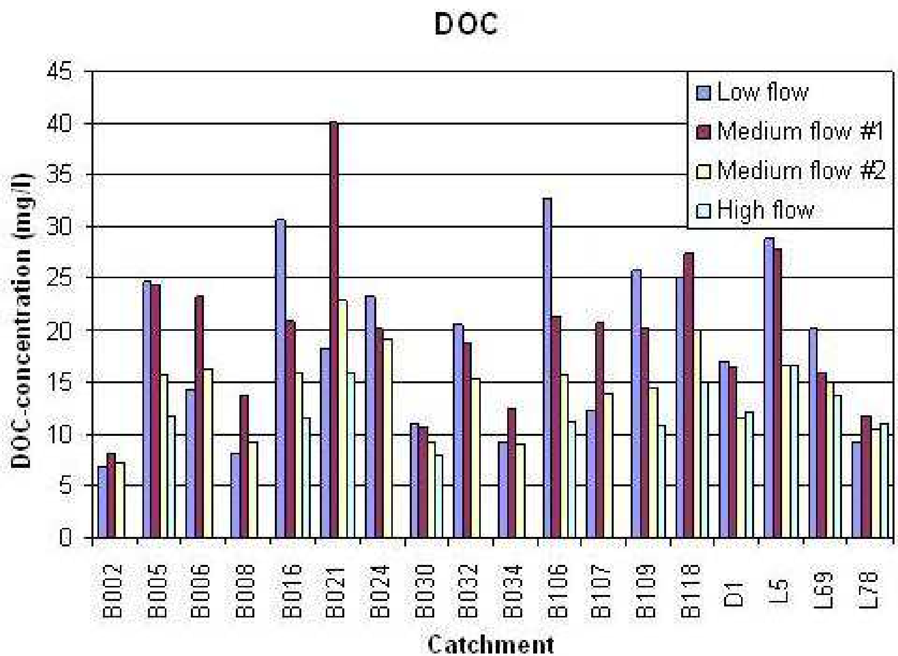

Fig. 7. DOC-concentrations for the 18 catchments during four flow situations.

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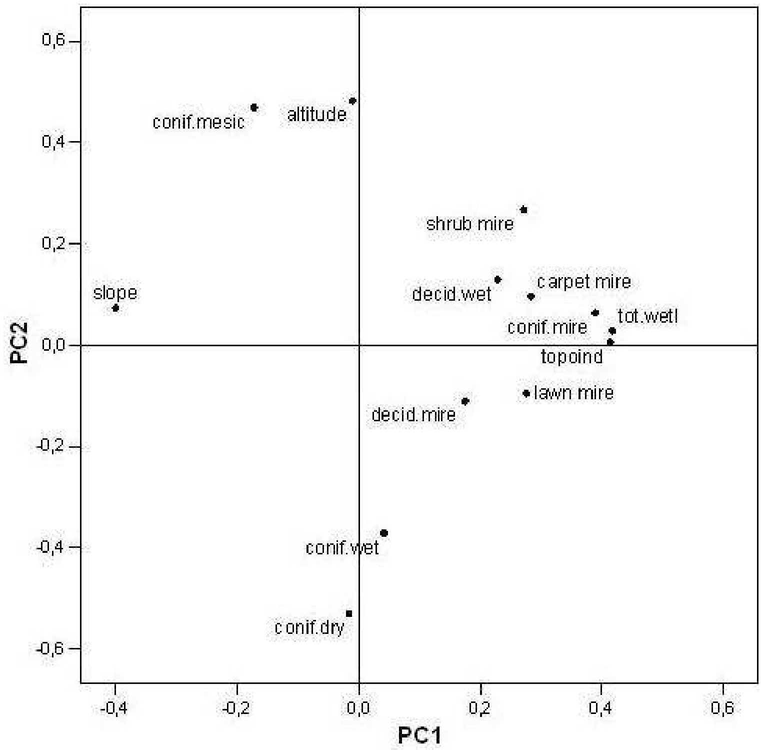

Fig. 8. PCA analysis of the most significant topographic and vegetation variables. The axes represent loadings for PC1 and PC2. The topographic variables included were mean altitude, mean slope and mean topographic wetness index. The vegetation variables were total wetland and variables no. 1–2, 4–5 and 7–11 in Table 3 (calculated as percentages of each catchment).

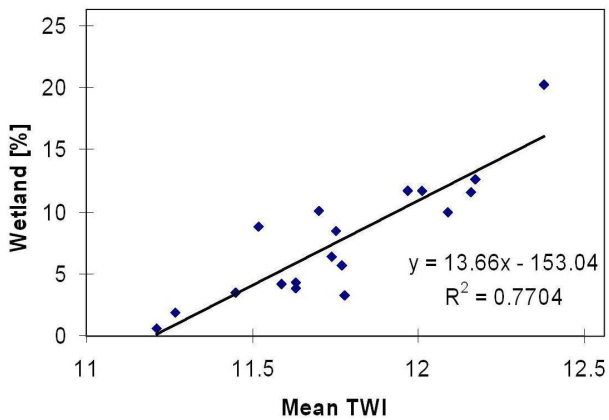

Fig. 9. Relationship between mean topographic wetness index and wetland percentage.

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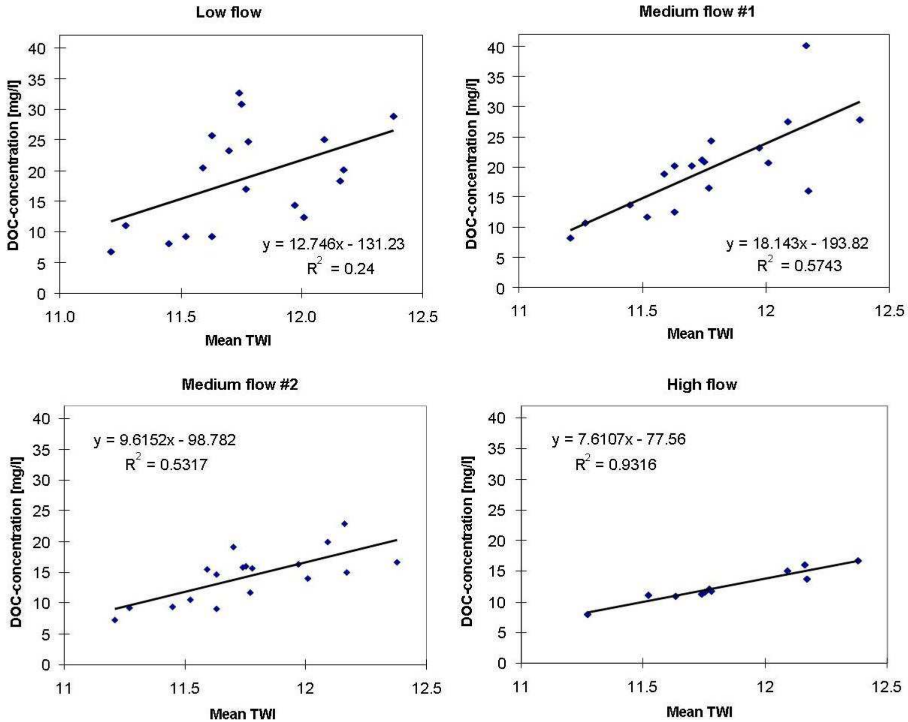

Fig. 10. Regressions between mean topographic wetness index and DOC in the four flow situations.